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Fuel Cell Technology Program  
Contract Summary Report  
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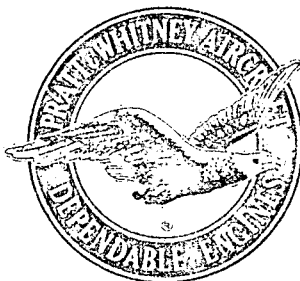
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## FOREWORD

This Fuel Cell Technology Program Contract Summary Report was prepared by Pratt & Whitney Aircraft Division of United Aircraft Corporation, South Windsor Engineering Facility, South Windsor, Connecticut in accordance with the requirements of Exhibit C, Paragraph 2.3.2 of NASA Contract NAS9-11034.

CONTENTS

	<u>Page</u>
1.0 SUMMARY	3
2.0 FUEL CELL SYSTEM STUDIES	3
3.0 TECHNOLOGY ACTIVITIES	6
3.1 High Power Density Cell	6
3.2 Open Cycle Cooling and Water Removal	8
3.3 Gas Circulators and Static Water Removal	11
3.4 Gas Purifiers	13
4.0 DEMONSTRATOR MODEL TEST	15
5.0 COMPLEMENTARY ENGINEERING	17

ILLUSTRATIONS

<u>Figure No.</u>	<u>Caption</u>	<u>Page</u>
1	Comparison of Baseline Requirements	3
2	Shuttle Power System Electrical Schematic	5
3	Fuel Cell System Studies	5
4	High Power Density Cell	6
5	Open Cycle Heat and Water Removal	9
6	Intercell Evaporative Cooling Assembly	9
7	Wet Bulb Humidity Sensor	10
8	Breadboard Power System	10
9	Oxygen Driven Coolant Pump	12
10	DM-1 Hydrogen Jet Pump	12
11	DM-1 Schematic	15

## 1.0 SUMMARY

A fuel cell technology program was established under NASA contract NAS9-11034 to advance the state-of-the art of hydrogen-oxygen fuel cells using the P&WA PC8B technology as the base. The major tasks of this program consisted of 1) fuel cell system studies of a Space Shuttle powerplant conceptual design (designated Engineering Model -1, EM-1) supported by liaison with the Space Shuttle Prime Contractors; 2) component and subsystem technology advancement and; 3) a Demonstrator Powerplant (DM-1) test.

Fuel cell system studies, with the EM-1 as the focal point of design activities, included determination of voltage regulation, specific reactant consumption, weight, voltage level and performance characteristics. These studies provided the basis for coordination activities with the Space Shuttle vehicle prime contractor. Interface information, on-board checkout and in-flight monitoring requirements, and development cost data were also provided as part of this activity. Even though the two vehicle primes had different voltage requirements (115 volts in one case and 28 volts in the other), it was concluded that either option could be provided in the fuel cell power system by the electrical hook-up of the cells in the stack.

Component and subsystem technology activities included four areas of interest. These were: 1) the high power density cell, 2) reactant purifiers, 3) gas driven circulators, and 4) open cycle heat and water removal.

The objectives of the high power density cell effort were to extend the cell operating life and to provide greater energy delivery capability. A single cell exceeded the NASA goal of 5,000 hours, having operated more than 10,000 hours with performance at that time still above initial performance. A 6-cell stack experienced a cell failure at 3,260 hours, however, it did exceed the NASA equivalent energy delivery goal.

The objective of the reactant purifier program was to provide a reactor which when used with a scrubber, would minimize any detrimental effect on a powerplant of operating on propellant grade reactant gases containing carbon dioxide and hydrocarbons. Platinum, Palladium and Rhodium catalysts were tested in a reactor to catalytically convert the trace hydrocarbons to carbon dioxide for removal by a scrubber. The Rhodium catalyst was found to be most effective.

The objective of the gas driven circulator activity was to provide a hydrogen pump and a coolant pump which used the stored pressure energy of the supply reactants. Their use would eliminate electric motors and parasitic electric loads from the fuel cell system. The use of a gas driven hydrogen circulator necessitated the development of a static water separator to remove product water from the recirculating hydrogen stream. An oxygen driven coolant pump was built and endurance tested. A two stage hydrogen jet pump and static water separator were built and bench tested.

The objective of the open cycle heat and water removal subsystem effort was to provide an alternate mode of removing fuel cell powerplant waste heat and product water when the Space Shuttle vehicle radiator is inoperative. An intercell evaporator which vented steam overboard and a humidity sensing hydrogen/water vent system were designed to accomplish this objective. A four cell operating breadboard system test demonstrated the feasibility of this approach.

The objective of the DM-1 demonstrator powerplant task was to demonstrate the fuel cell technology at the system level for a 2000 hour period. The powerplant demonstrated the ability to operate at low and high reactant supply pressures, bootstrap (self-start) capability, spike transient capability to 10.5 kw, open cycle water removal for periods longer than one hour and unattended automatic operation. However, the 2000-hour test objective was not met. At 610 hours of operation, the test was interrupted because of a gear failure in the Block II Apollo hydrogen pump and at 750 hours the test was terminated by a gas crossover failure of cell number four.

The pump problem was determined to be the result of operation at an undamped natural frequency which caused accelerated gear wear. Teardown inspection of the stack revealed a uniform physical distress on the cathodes of all the cells. Analysis of this evidence indicated that the stack had been subjected to an overpressure condition, however, review of the test data recorded during steady-state operation did not show such an incident. A series of hydrogen, oxygen and coolant overpressure tests were performed on identical cells. The physical condition of the DM-1 cells was duplicated by a 45 psi hydrogen overpressure. It was concluded from this that the coupled regulator (breadboarded with two Apollo regulators modified to provide remote sensing) produced a temporary pressure imbalance, permanently distorting the electrodes causing a performance loss and an uneven heat transfer and current density situation. This subsequently caused a localized matrix dryout and reactant gas crossover.

Although it is theorized that the DM-1 failure was caused by the regulator and that a reliable, flight quality regulator would have a much lower probability of causing such an event, it was decided that follow on activity should be directed toward making the cell less susceptible to reactant crosspressures.

## 2.0 FUEL CELL SYSTEM STUDIES

Fuel cell system studies, with the Engineering Model (EM-1) conceptual design as the focal point, evaluated all of the technology advancement improvements such as open cycle heat and water removal, high power density (HPD) cell, gas driven pumps and static water separator, and reactant purifiers. The powerplant was sized for 5 kw sustained power and 10 kw peak power at  $\pm 5$  percent voltage regulation. This design served as a baseline for liaison activities with the Prime Contractors, North American Rockwell (NR) and McDonnell-Douglas Aircraft Corporation (MDAC), and for technology program planning. A comparison of the baseline requirements for each of the Prime Contractors is shown in Figure 1.

CHARACTERISTIC	NASA GUIDELINES	NR	MDAC
• SUSTAINED POWER - KW	5	7	7
• PEAK POWER WITHIN VOLTAGE REGULATION - KW	10	10	14
• MINIMUM POWER WITHIN VOLTAGE REGULATION - KW	0	1.5	0
• VOLTAGE REGULATION BAND	26.6-29.4V $\pm 5\%$	27.6-31.0V $\pm 6\%$	108-126V $\pm 7.7\%$
• SPECIFIC REACTANT CONSUMPTION - LB/KWH	.8	-	-
• REACTANT SUPPLY - MIN PRESSURE - PSIA	20 & 200	200	200
- GRADE	PROPULSION	FUEL CELL	PROPULSION
• OPEN CYCLE COOLING	YES	NO	NO
• OPEN CYCLE WATER REMOVAL	YES	NO	YES
• OPERATING LIFE - HR	5000	5000	5000

Figure 1 - Comparison of Baseline Requirements

Design trade-off data requested by the Prime Contractors were generated to evaluate the impact on the Space Shuttle power system for variations in:

- Power Level
- Voltage Regulation
- Voltage Level
- Open Cycle Heat and Water Removal
- Reactant Supply Pressure

The power level and voltage regulation selected by the individual Prime Contractors resulting from their vehicle trade studies were essentially the same at 7 kw sustained power and  $\pm 6$  to 7.7 percent voltage regulation. The variation in the spike load capability of 10 to 14 kw reflected the individual power management philosophies employed but had little impact on the power-plant design.

The voltage level selected by the Prime Contractors was significantly different as one selected 29 volts while the other selected 120 volts. Either option can be provided in the fuel cell power system by the electrical hook-up of the cells in the power stack.

The open cycle heat and water removal objective of the technology program was to provide an alternate means of heat and water removal during launch and re-entry in the event that the spacecraft radiators were inoperative. Prime Contractor studies of preferred vehicle configurations did not conclude that this alternate mode of heat and water removal was necessary for a normal mission. However, there were indications that for some alternate vehicle configurations and possible contingency situations, the open cycle mode of operation would be desirable. As a result of its demonstrated operation in this program, it was concluded that open cycle heat and water removal is feasible.

Reactant gas storage and supply system studies by the Prime Contractors indicated a high pressure system was preferable. A high pressure-reactant supply is preferable from a fuel cell powerplant standpoint also in that it allows high or low pressure operation and permits the use of either electric or gas driven pumps. Studies by the Prime Contractors did not indicate a clear advantage for either electric or gas driven pumps. The technology assessment or program cost consideration will determine the final choice.

An electrical schematic was produced at program completion to reflect the results of the power system studies and the integrated effort needed to achieve the Space Shuttle on-board checkout and flight monitoring requirements. This is presented in Figure 2.

The significant results of the design phase are summarized in Figure 3 and represent design inputs for a follow-on system development program.



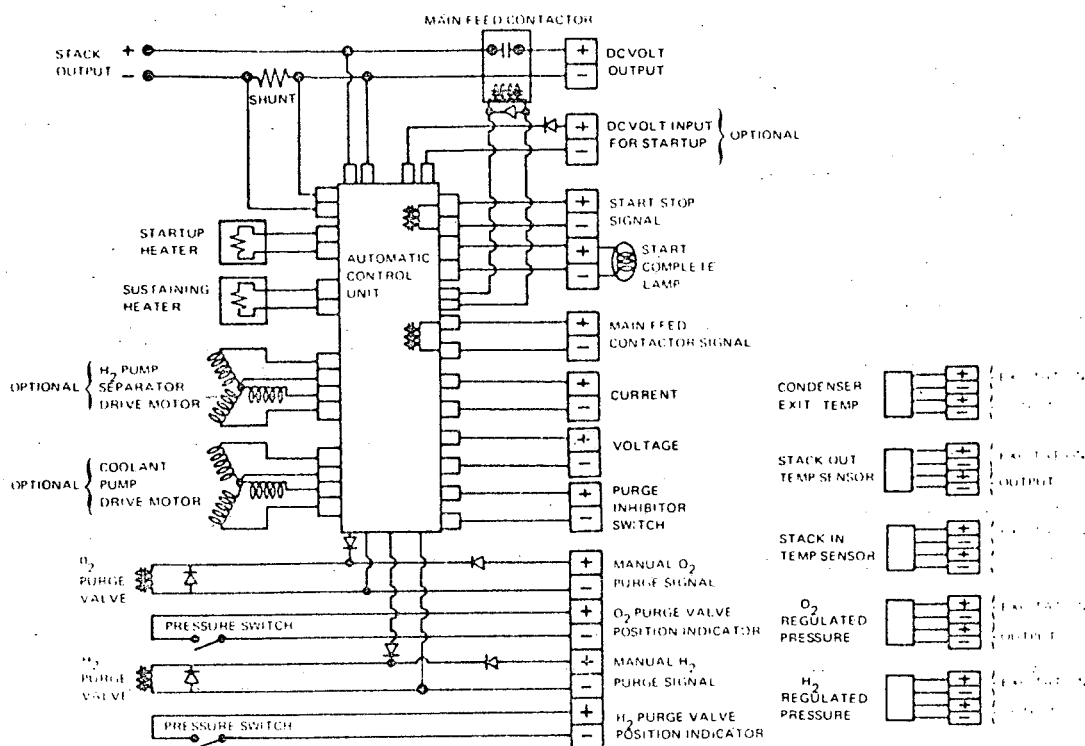


Figure 2 - Shuttle Power System Electrical Schematic

- TECHNOLOGY COMPATIBLE WITH REQUIREMENTS OF SHUTTLE PHASE B CONTRACTORS
- VOLTAGE LIMITS SHOULD BE AT LEAST  $\pm 6\%$
- OPEN CYCLE COOLING NOT NEEDED IN FUEL CELL
- OPEN CYCLE WATER REMOVAL MAY BE ADVANTAGEOUS
- CHOICE OF ELECTRIC OR GAS-DRIVEN PUMPS NOT SIGNIFICANT FROM SYSTEM VIEWPOINT
- VOLTAGE LEVEL DOES NOT APPEAR TO HAVE LARGE EFFECT ON POWERPLANT WEIGHT OR FUEL CELL PROGRAM COST

Figure 3 - Fuel Cell System Studies

### 3.0 TECHNOLOGY ACTIVITIES

#### 3.1 High Power Density (HPD) Cell

The HPD cell design was developed for this program, using the PC8B technology and materials as a base to meet the NASA goals of increased life and energy delivery. The HPD cell design increased the electrolyte inventory of each cell by approximately 2 1/2 times that of a PC8B cell. This was accomplished by including a sintered electrolyte reservoir plate in the cell assembly. The plate was placed in the hydrogen gas cavity and connected to the anode screen electrode assembly by contact pressure. Anode and cathode screen electrodes identical to the cathode screen electrode of the PC8B cell and a 0.010 inch asbestos matrix completed the cell assembly details. These items were assembled in a fiber glass hard frame as shown in Figure 4.

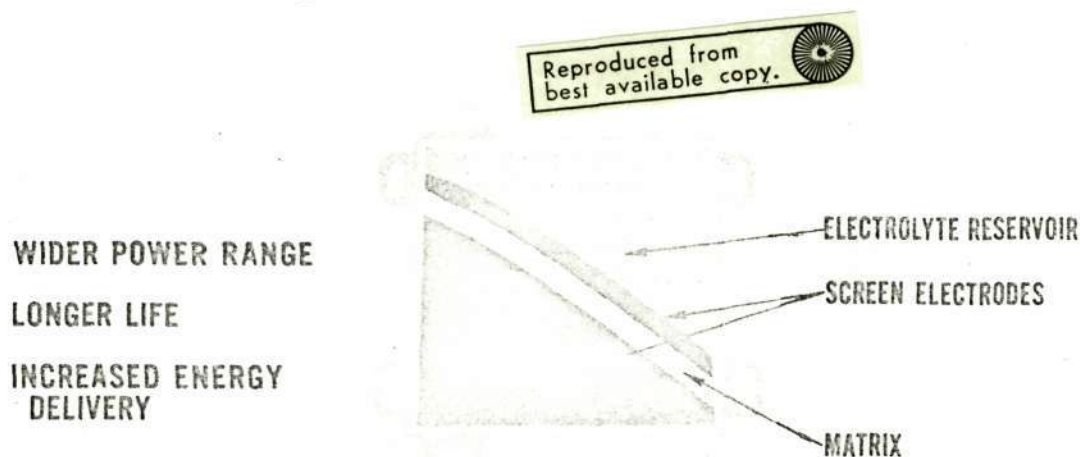


Figure 4 - High Power Density Cell

The initial cells were built and tested as single cells at a range of conditions considered for the demonstrator powerplant. Of the 4 initial cells tested, 2 failed because of electrical shorting between electrodes at metal hydrogen inlet and exit tubes. Improvement in subsequent cell design eliminated these tubes. A third single cell achieved 3580 hours of operation before a stand failure terminated the test by flooding the assembly with water. The fourth cell completed more than 10,000 hours of operation with no measurable performance decay.

A 6-cell rig was built with three separate configurations; standard HPD cells, HPD cells with high catalyst loaded cathodes, and HPD cells with a 0.015 inch thick matrix. Early testing indicated high decay of the high catalyst loaded cathode cells which were removed from the stack. Re-assembly and subsequent testing indicated a deficiency in the matrix/hard frame joint design of the unitized electrode assembly resulting in a performance loss of the cells.

Changes dictated by these experiences were made to the cell design and a 6-cell assembly to this design was built and began endurance testing at DM-1 conditions early in February 1971 with a 5000-hour test objective. Operation was scheduled on an automatic test stand requiring a minimum of operator surveillance. A performance loss on all cells was experienced following an automatic shutdown due to loss of facility power at 1410 hours. The performance recovered fully in 500 hours of subsequent operation although the cause was not defined and the test continued until 3300 hours of operation when failure of cell #3 terminated the test. A failure investigation indicated cell #3 failed because of a localized matrix dry out and experienced a crossover gas failure.

Although the 6-cell rig did not achieve the 5000-hour life, it did exceed the equivalent energy delivery NASA goal. This plus the 10,000-hour single cell operation with no decay provide a means of measuring the present design against the NASA program goals.

Additional improvements in the cell design are possible by incorporating the results of design support tests also conducted during this program. The life potential of the base cell is known to be affected by the change in the electrolyte carbonate level. This results from reactant gas transported carbon elements and corrosion products of compounds in the cell assembly such as epoxy and asbestos. An investigation into alternate frame materials identified Noryl® or Arylon® as suitable candidates. The use of EPR as a bonding agent was also evaluated and found to be essentially inactive in this environment. A follow-on program then could expect to make significant improvement in the cell life and energy delivery and possibly in cell weight.

### 3.2 Open Cycle Heat and Water Removal

Open cycle heat and water removal was explored in this program to provide an alternate mode of removing fuel cell waste heat and product water when the vehicle radiator is inoperative during launch and re-entry. A schematic diagram of the system is shown in Figure 5. Heat removal is accomplished through an intercell evaporator which is shown in Figure 6. Cooling water is introduced into the evaporator through the water pressure regulator on command from a reactor stack temperature sensor. The water is converted to steam in the hydrophobic separator by the waste heat from the reactor stack cells and is vented overboard. The desired temperature is maintained by the steam vent back pressure regulator.

Proper electrolyte concentration is normally maintained in the reactor stack by the closed loop condenser and water separator. In the event that adequate cooling is not supplied to the condenser, the humidity sensor will sense an above normal moisture content of the recirculating hydrogen stream and will activate an overboard hydrogen/water vent. The valve is operated intermittently as required to maintain the proper electrolyte concentration.

A design study indicated a condensing type humidity probe would provide maximum system reliability. This probe is shown in Figure 7. In this probe, a cooling coil in the hydrogen gas stream condensed water vapor which was then wicked to the tip of a wet bulb thermocouple thereby indicating wet bulb temperature. This signal, coupled with a dry bulb temperature, provided a discrete signal which indicated the cell electrolyte concentration. Porous ceramic or fritted glass were selected as prime candidate materials for the wick as they are both inert and have structural stability. The probe was tested on the bench, used in the DM-1 powerplant test and in the 4-cell breadboard power system test.

The breadboard power system test used a four-cell stack of 0.15 ft<sup>2</sup> cells with internal hydrophobic separators or water boilers. This rig had been built and tested during an earlier Air Force contract and is shown in Figure 8. Difficulty had been experienced in the cell stack in sealing the gases, water and steam from overboard leakage prior to completion of the Air Force Contract.

Changes in unitized electrode and hydrophobic separator frames were included and 40 hours of operation were accumulated which included 21 hours of open cycle operation at current densities up to 1000 amps/ft<sup>2</sup>. This testing served to demonstrate that the open cycle heat and water removal concept is feasible, however, the durability of the present frame and seal materials of the hydrophobic separator and the cell is inadequate. Any follow-on activity on this subsystem, then, should emphasize material improvement.

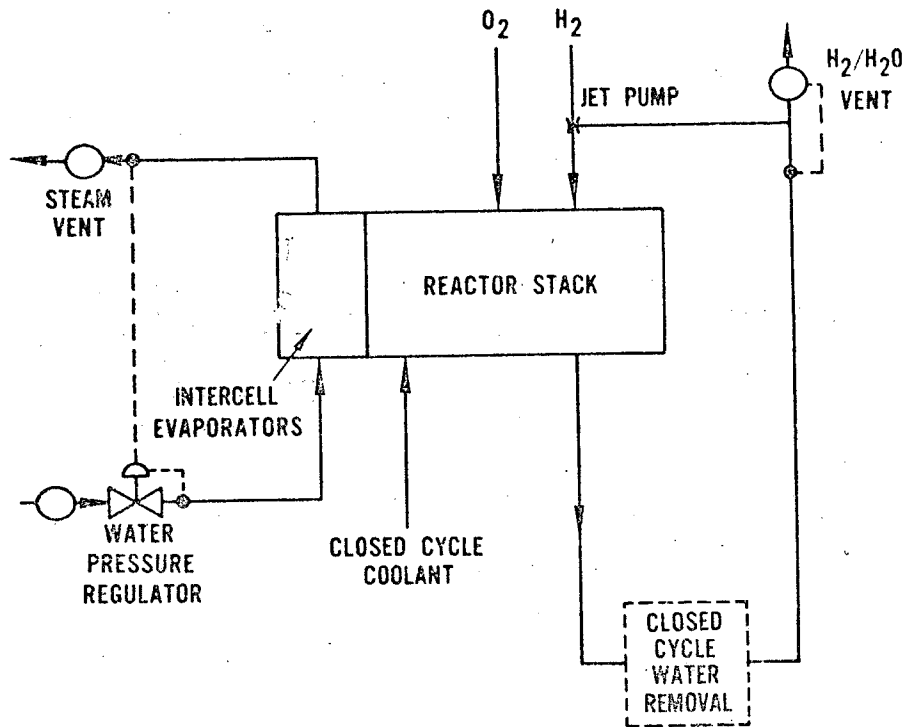


Figure 5 - Open Cycle Heat and Water Removal

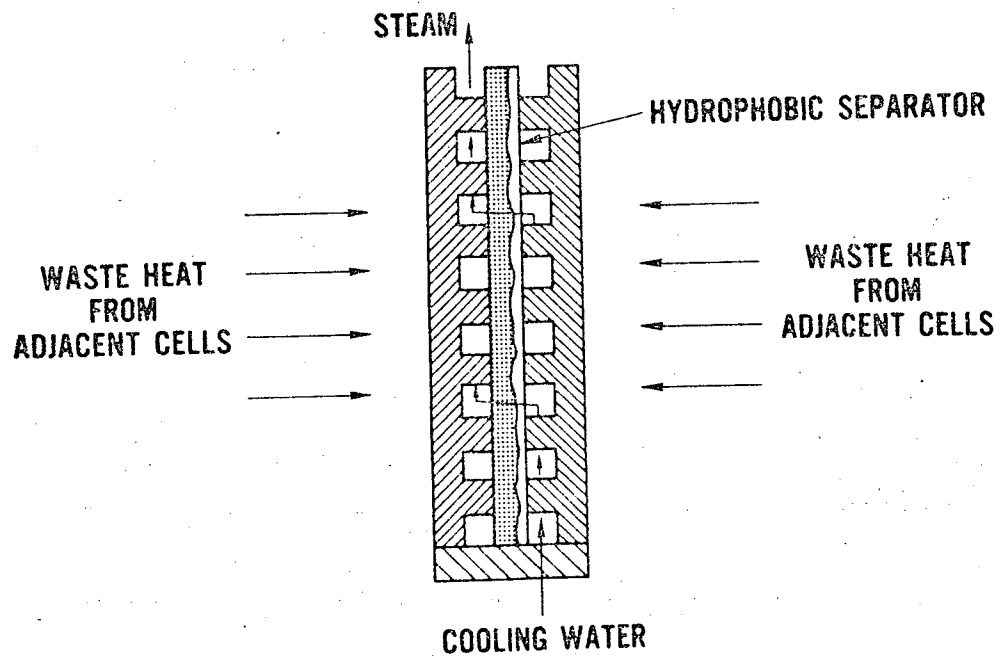


Figure 6 - Intercell Evaporative Cooling Assembly

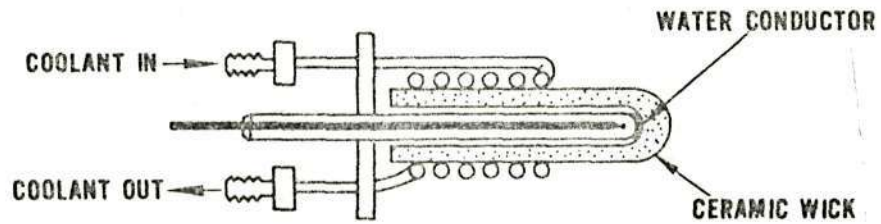


Figure 7 - Wet Bulb Humidity Sensor

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Figure 8 - Breadboard Power System

### 3.3 Gas Circulators and Static Water Separator

Studies were conducted early in the technology program to define gas driven circulators which could replace the motor driven coolant and hydrogen pumps of the Apollo fuel cell system. Such devices would reduce the parasite power and improve system reliability by eliminating the electric motor drives. The study indicated an oxygen driven coolant pump could provide sufficient coolant flow to remove the cell waste heat over a very wide range of fuel cell power. Likewise, a two stage hydrogen jet pump could circulate water bearing hydrogen through the cells proportional to demand power provided the inlet supply pressure was  $>200$  psi. A static water separator was also designed and built to be used with the hydrogen jet pump and remove water from the condenser exit.

The oxygen driven coolant pump was a double acting diaphragm pump using fuel cell consumed oxygen gas to pump the liquid coolant through the power system. The coolant flow rate was therefore proportional to the fuel cell gas consumption and hence the cell heat rejection. Figure 9 shows the pump details. Excellent power turndown capability resulted. The program conducted evaluated pilot valve wear, alternate diaphragm material and construction life capabilities until satisfactory results permitted the initiation of an oxygen driven coolant pump operating life test. 2014 hours of operation were demonstrated on this test. Even though difficulties were encountered with test stand contaminants and an early diaphragm design, the test demonstrated the capability of this pump to meet the requirements of the DM-1 power system.

Design studies indicated that a two-stage hydrogen jet pump could satisfy the flow turndown (maximum power flow/minimum power flow) required for the hydrogen recirculation in a Space Shuttle power system. A two-stage series hydrogen ejector with a pressure actuated secondary flow valve was designed to satisfy DM-1 flow requirements. This pump is shown in Figure 10. In this design, the primary nozzle is always in operation. As fuel cell power output increases, the hydrogen gas supply pressure provided to the pump by the remote sensing regulator increases. When this pressure exceeds the preset spring pressure of the secondary flow valve, the valve will open allowing hydrogen flow to the secondary nozzle, thereby providing the required recirculation flow to remove product water from the cells. The pump was built and bench tested. System flow and pressure drop requirements were met for a power range of approximately 1 kw to 10 kw. Below 1 kw, the recirculated flow was below minimum requirements. Design modifications to improve the low power performance of the pump have been identified.

The static water separator design required considerable design test support. This activity centered on evaluation of available wick and separator porous material to meet pore size, flow rate and bubble pressure requirements in addition to being inert, easily wetted and could be sterilized. Fritted glass

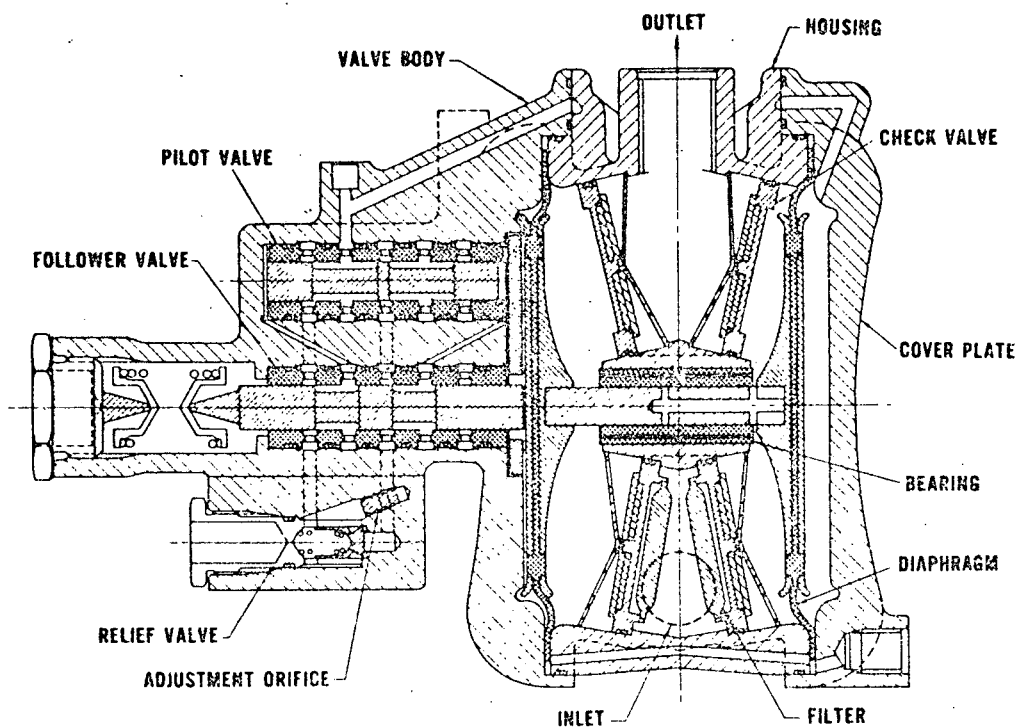


Figure 9 - Oxygen Driven Coolant Pump

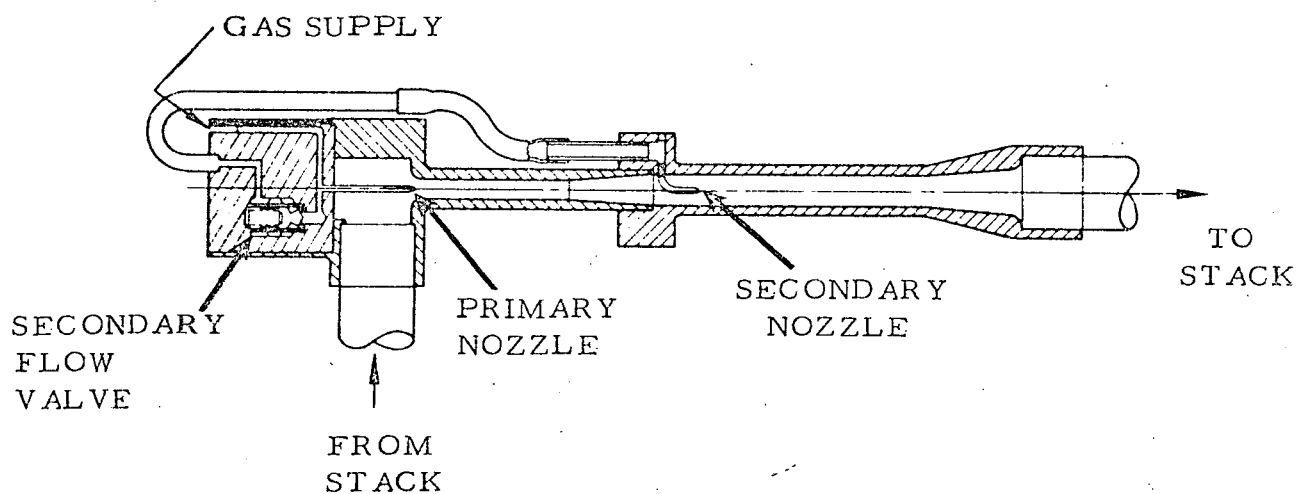


Figure 10 - DM-1 Hydrogen Jet Pump



and porous ceramics met these requirements best of all materials tested. Tests of possible flow path geometries were made to determine a design with low pressure loss with maximum tortuosity. A labyrinth geometry was selected and sample separator modules were built. A series of 5 inch parallel labyrinths were tested with unsatisfactory results. As the hydrogen flow rate is variable with the hydrogen jet pump, considerable difficulty was experienced in supplying uniform parallel flow to the individual modules. At the completion of the program, an alternate design was recommended which would eliminate this problem.

An alternate hydrogen pump separator was also evaluated during this program. This motor driven pump was a direct drive drag pump with a dynamic water separator. This pump eliminated the carbon vanes and the gear drive life limiting features of the Apollo pump separator. An existing pump was bench tested at both low and high system pressures and exceeded the requirements of the DM-1 using 20 watts of power. Minor deficiencies noted were the assembly difficulty associated with the particular design clearances and a high inertia rotor which required a long startup period. Design changes were made and new parts placed on order.

### 3.4 Gas Purifiers

Early NASA studies indicated vehicle logistic and hardware simplifications would result from using propellant grade gas in the fuel cells. Propellant grade oxygen specifications allow a hydrocarbon content of 55 ppm. If these quantities are experienced, it may be necessary to remove this contaminant from the oxygen used as a fuel cell reactant. This can be accomplished by converting the hydrocarbon to carbon dioxide and then scrubbing the carbon dioxide from the gas. This program was to evaluate existing CO<sub>2</sub> scrubber technology on multi-cell operating life and DM-1 tests, and develop design information for a hydrocarbon oxidizer catalyst.

Utilizing available CO<sub>2</sub> scrubber experience at P&WA, CO<sub>2</sub> scrubbers were designed, built and installed on the operating life 6-cell test, and on the DM-1 Power System. The 6-cell test also had a CO<sub>2</sub> detector available to test its effectiveness. The propellant grade oxygen gas was noted to have CO<sub>2</sub> content < 4 ppm and generally much lower. The scrubbers, which were made by Union Carbide, removed cell CO<sub>2</sub> down to 1/2 ppm throughout the testing.

Selected catalysts were tested using oxygen containing approximately 55 ppm of methane to obtain design information for converting the hydrocarbon to carbon dioxide. The catalysts tested were:

- . 0.5% Rhodium on alumina
- . 0.5% Palladium on alumina
- . 0.5% Platinum on alumina
- . 10.0% Platinum on alumina

The activities of these catalysts in converting the methane in oxygen were determined at various levels within the temperature range of 200°F to 800°F and the pressure range of 0 psig to 60 psig.

The Rhodium catalyst was the most active in removing methane from oxygen at each temperature level. The other catalysts either had lower activity or decayed more rapidly. Increasing the pressure further increased the catalyst activity.

It was concluded that this design approach was feasible for a Space Shuttle design in the event propellant grade gases are eventually selected for use by the fuel cells.

#### 4.0 DEMONSTRATOR MODEL TEST

The DM-1 power system was a fully automatic 28-volt d.c. 5 kw rated electric power supply. The power system was coupled with an automatic start/stop sequencer and an Automatic Data Recording (ADR) system. The automatic start/stop sequencer brought the power system to full operation in approximately 15 minutes following actuation of a single start switch, and the ADR computer provided automatic purge control and failure and warning detection throughout the test. The DM-1 began testing in May 1971 to demonstrate fuel cell technology at the system level for a 2000-hour period. At 750 hours of operation, the test was terminated by a gas cross-over failure of cell number four.

The DM-1 schematic is presented in Figure 11.

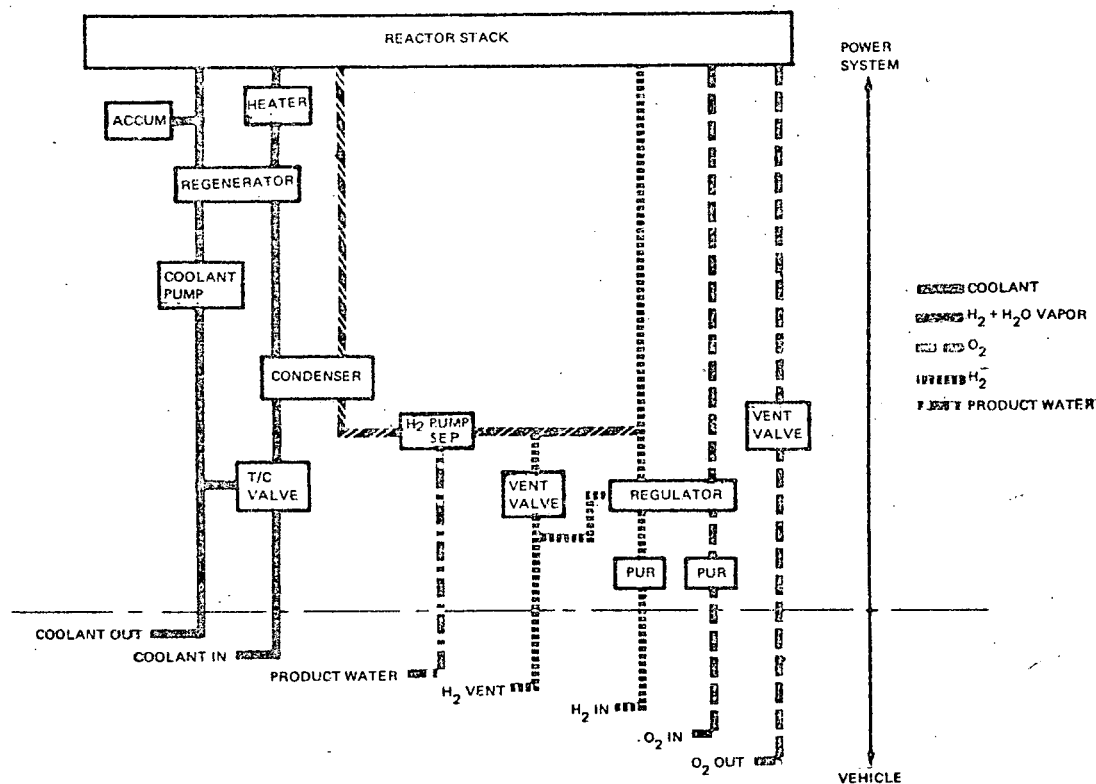


Figure 11 - DM-1 Schematic

The test program evaluated the power system performance and operating characteristics during bootstrap starts at low and high reactant supply conditions. 200 channels of instrumentation provided digital printout of pressure, temperature, voltage and current for all significant parameters during steady-state operation to 10 kw. In addition, extensive stack temperature data was collected. Transient recordings of overall voltage and current were made during transient load variation between open circuit and 10 kw.

Use of the Automatic Data Recording (ADR) permitted Power System operation completely unattended for extended periods of time. Furthermore, computer monitoring similar to that contemplated for the vehicle was accomplished by establishing normal operating parameters which when exceeded would trigger a shutdown and inerting procedure.

Another significant demonstration during the test was uniform cell-to-cell performance of the complete stack with high levels of inerts using an oxygen recirculator. In addition, the oxygen recirculator demonstrated significant purge efficiency improvement by increasing the ampere hours between purges allowable for any given performance degradation.

Test anomalies were experienced throughout the test but, with the exception of two instances, were identified and corrected during the test period. The two remaining at the termination of the DM-1 test were the Block II Apollo hydrogen pump gear failure at 610 hours of operation, and Cell #4 gas crossover failure at 750 hours. A failure investigation was conducted for each at the end of the program. The Apollo hydrogen pump problem was the result of operation of this pump at an undamped natural frequency condition which resulted in an accelerated gear wear rate and resultant failure.

The Cell #4 failure had been preceded by an average 85 mv/cell loss on all cells following repair of the hydrogen pump at 610 hours. A complete failure investigation revealed a uniform physical distress on the cathodes of all the cells. Analysis of this evidence indicated that the stack has been subjected to an overpressure condition, however, review of the test data recorded during steady-state operation did not show such an incident. A series of hydrogen, oxygen and coolant overpressure tests were performed on identical cells. The physical condition of the DM-1 cells was duplicated by a 45 psi hydrogen overpressure. It was concluded from this that the coupled regulator (breadboarded with two Apollo regulators modified to provide remote sensing) produced a temporary pressure imbalance, permanently distorting the electrodes causing a performance loss and an uneven heat transfer and current density situation. This subsequently caused a localized matrix dryout and reactant gas crossover.

Although it is theorized that the DM-1 failure was caused by the regulator and that a reliable, flight quality regulator would have a much lower probability of causing such an event, it was decided that follow-on activity should be directed toward making the cell less susceptible to reactant crosspressures.

Significant demonstrations of the test program are summarized below:

- . 750 hours of operation
- . 16 automatic starts and stops
- . Operation at low and high reactant gas supply pressures
- . Spike transients at 10.5 kw
- . Sustained operation at 10 kw for 6 minutes
- . Operation on fuel cell and propulsion grade reactants
- . Open cycle water removal for 1 hour

## 5.0 COMPLEMENTARY ENGINEERING

The reliability program consisted of reliability analyses and trade-off studies conducted during the EM-1 conceptual design and testing phases of the DM-1 program. Results of these analyses and trade-off studies were used to direct design efforts toward minimizing the probability of a powerplant failure. The analyses also provided criteria for follow-on program reliability and test planning tasks.

Both powerplant and component Failure Mode and Effect Analyses (FMEA) were prepared to a level of detail consistent with the existing design definition at each particular phase of the program. Special stress was placed on early input to the design concept from the FMEA. The powerplant FMEA was a general study which considered the effects of various failure modes on the powerplant to provide an overview of the conceptual design.

The detailed component level FMEA's were performed on the (a) reactor stack, (b) hydrogen jet pump, (c) oxygen-driven coolant pump, (d) coupled regulator, and (e) humidity sensor probe. The purpose of these FMEA's was to evaluate the effect of individual part failure modes on the component and on the total fuel cell powerplant. Information from these components FMEA's served as one source for the derivation of design criteria incorporated in the component design specifications.

Component level FMEA's were also performed on less well defined components and on all the remaining ancillary components in the DM-1. Information from these FMEA's will serve as a basis for more detailed analysis in subsequent follow-on programs.

Reliability trade-off studies were conducted to provide data for designing a fuel cell powerplant. Consideration was given to mission reliability, redundancy, maintainability, operating life and failure effect. These studies included investigations of powerplants with various voltage levels, powerplants with either a gas-driven or an electric-driven circulating pump, and diaphragm redundance studies for the oxygen-driven coolant pump.

Additional reliability studies included reviews of the test facilities used for the endurance testing of the 6-cell multicell rig and the DM-1 powerplant and were conducted to minimize the probability of a fuel cell stack failure caused by an external (facility) source.

During the execution of this fuel cell program, the groundwork was set for achieving the safety goal of not contributing to a vehicle failure and not endangering personnel during handling and support. The main contributions to this goal were:

- Establishment of a line of communication for the reporting and dissemination of system safety information.
- Identification of potential hazards within early designs.
- Gathering and dissemination of pertinent safety information required for further analyses.
- The identification of safety action items for resolution in subsequent follow-on programs.